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13. ABSTRACT (Maximum 200 words)

THE PURPOSE OF THIS STUDY WAS TO DETERMINE THE FEASIBILITY OF AN INTERIM GROUND WATER CONTAINMENT/TREATMENT SYSTEM FOR THE AREA NORTH OF BASIN F. NEW INFORMATION FROM BORING LOGS AND A GEOPHYSICAL INVESTIGATION SUGGESTS THAT THE BEDROCK FORMATION IN THE AREA IS DIFFERENT THAN ORIGINALLY ASSUMED.

OF THE TWO ALTERNATIVE SYSTEMS SUGGESTED, AN HYDRAULIC BARRIER OR A SLURRY WALL SYSTEM, THE FORMER IS RECOMMENDED.

MAPS SHOWING BEDROCK FORMATIONS AND CONCENTRATIONS OF CONTAMINANTS ARE INCLUDED.

APPENDIX A IS A REPORT DONE BY GREAT PLAINS GEOPHYSICAL, INC. ENTITLED "RESULTS FROM SHALLOW SEISMIC REFLECTION SURVEYS NEAR RESERVOIR F." THE PURPOSE OF THE SURVEY WAS TO DEFINE THE BEDROCK SURFACE BENEATH THE UNCONSOLIDATED ALLUVIAL LAYER. THE FIELD TECHNIQUE USED WAS SHALLOW SEISMIC REFLECTION.

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FEASIBILITY ANALYSIS

BASIN F INTERIM WELL SYSTEM

ROCKY MOUNTAIN ARSENAL

FILE COPY

Rocky Mountain Arsenal
Information Center
Commerce City, Colorado

December 1987

OMAHA DISTRICT, U.S. ARMY CORPS OF ENGINEERS

93-26657

PURPOSE: The purpose of this report is to summarize the efforts made in evaluating the feasibility and technical requirements of a hydrologic barrier system north of Basin F at Rocky Mountain Arsenal.

AUTHORIZATION: This project is authorized by the Office of Program Manager, Rocky Mountain Arsenal Contamination Cleanup(PM,RMA), dated 8 December 1986, as defined by the Memorandum of Understanding(MOU) between PM,RMA and the Omaha District, dated 22 August 1986.

SCOPE AND CRITERIA: The Scope of Work was developed in a meeting on 9 December 1986 between representatives of the PM,RMA and the Corps of Engineers. During the course of the meeting, the Omaha District was directed to determine the design feasibility of such a system with the following criteria:

-The system is to include a hydraulic ground-water barrier using approximately two-to-four dewater wells and approximately twice that number of recharge wells.

-The locations of bedrock channels, based on the available data, was provided to the Omaha District for use in the study.

-The saturated thicknesses, aquifer transmissivities, and other data required for evaluation and design could be obtained from previous studies at RMA.

STUDY DESCRIPTION: This study was to determine the feasibility of an Interim ground-water containment-treatment system for the area north of Basin F at Rocky Mountain Arsenal. Early phases included the assembly and review of available site-specific geologic and hydrologic data. This review included boring logs, water level readings, hydrologic studies, and preliminary system evaluations developed by various Army agencies and contractors. These data were assembled and used to develop a hydrologic model of the project area, based on the 1971 Prickett-Lonnquist computer model. Bedrock conditions for the model were based on a preliminary bedrock map supplied by Waterways Experiment Station(WES).

INITIAL PROJECT DEVELOPMENT: Several data gaps became apparent during development of the model, principally in the eastern portion of the study area where very few wells or borings have been located. At the request of PM,RMA and the Omaha District, additional borings were obtained by Environmental Science and Engineering, Inc.(ESE). The boring data included bedrock elevations, water levels, aquifer thicknesses, gradation analyses, and chemical analysis information from four borings placed within the proposed system boundaries.

The borings were located in areas assumed to have relatively deep, narrow bedrock channels containing significant saturated thicknesses, based on the available data. The boring data from ESE indicated that deep channels were not located at those points. As a result, the modeling and

analysis performed to that point was not considered valid, and more bedrock channel data was required.

GEOPHYSICAL SURVEYING AND ANALYSIS: The Omaha District obtained the services of Golder Associates and their subcontractor, Great Plains Geophysical, Inc. to obtain bedrock profiles along the proposed well lines. This firm utilizes seismic reflection survey methods and computer processing of data to determine the nature of subsurface features. The results of this survey indicated that the bedrock channels were much broader and shallower than was originally assumed.

The shallow seismic reflection profiles apparently indicate the locations of the shallow bedrock channels fairly accurately. However, the actual depths of the channels are not as readily apparent due to dip-related complexities from the channel sides. The bedrock elevations were correlated with nearby borings and should be accurate in most locations, although actual depths of channels with no confirmation borings may be off by several feet. The bedrock map which is included in the September 1, 1987 report by Great Plains is their interpretation. The cross-sections along the profile lines are considered fairly accurate and were used in the computer modeling.

Based on new data derived from borings and reflection-seismic surveys, the nature of the ground-water conditions northeast of Basin F has been reinterpreted. The deep saturated bedrock channels as previously interpreted are now interpreted as broad bedrock channels with a typical saturated thickness of eight feet or less. The deep bedrock channel interpretation was ideal for the application of a two-to-four well hydrologic barrier system. The new interpretation provides less favorable conditions for such a system, due to the broad area of saturation and the small saturated thickness.

GROUND-WATER MODELING: The previously developed computer model of the study area was modified to approximate the new bedrock data. Preliminary evaluations indicate that a well system with approximately 10 wells spaced at 80 to 100 feet and pumping at low rates can contain much of the contaminant plume.

Figure 1 shows the study area as set up in the computer model, with the original concept of the bedrock surface. Figure 2 shows the revised approximation of the bedrock surface as used in the modeling. Figure 3 shows the approximate original head contours.

Figure 4 shows head contours in a simulation of a pumping scheme with dewater wells along column 9, pumping at a total rate of 110 gpm. A row of recharge wells is located along column 13. The difference in head between the recharge line and the dewater line is less than 0.5 feet, indicating only a marginal capacity to reverse the gradient at this rate.

An increase in the pumping rate can help reverse the gradient and provide a more positive capture of contaminants. Figure 5 shows head

contours in a simulation of a system pumping a total of 165 gpm. Again, the dewater wells are along column 9 and the recharge wells are along column 13. The difference in head values between the dewater and recharge lines is slightly over 0.5 feet, only a marginal improvement at a significant increase in system capacity. Since this pumping rate is approximately 2.5 times the estimated flux, a major portion of this water is recycled "clean" water from the recharge wells. A reasonable capacity for the well system would be somewhere between 110 gpm and 165 gpm.

Figures 6 through 9 show various contamination concentrations in the study area. A comparison of these maps to the simulations shown on Figures 4 and 5 shows that the majority of the plume flow is contained within the system.

POTENTIAL DESIGN PROBLEMS. Some of the potential problems with a hydrologic barrier well system in the study area are as follows:

(1) Due to the small saturated thickness, the well screens must be placed in highly permeable sands and gravels for maximum efficiency. the data indicate that highly permeable sands and gravels occur over most of the site, but some areas are likely to be less permeable.

(2) With the small saturated thickness and the resulting low pumping rates anticipated, the radius of influence around each well will be small. This results in the requirement for many closely-spaced wells for the intersecting cones of depression to form a barrier, and still allows for the possibility of breakthrough of contaminated ground water between wells.

(3) At reasonable pumping rates, the gradient reversal at the system is minimal, with a maximum head difference of less than one foot between the recharge and dewater well lines. The piezometric surface returns to near-original conditions within 2 to 3 days of system shutdown. This does not allow a significant safety factor for positive cutoff.

(4) Seasonal fluctuations may reduce the piezometric surface in the area, resulting in the drying up of marginal wells. This would require somewhat more complex controls and operations to perform efficiently.

Although such a system cannot be considered a positive cutoff, it would remove a major percentage of the contaminant near the source at Basin F and significantly reduce the contaminant load to the North Boundary system.

ALTERNATE SYSTEMS: Two major alternative systems are available, depending on the degree of containment required. One system attempts only reduction of the contaminant load, and the other provides total cutoff and treatment.

An alternate well system could be developed to remove contaminated ground water from the channel areas only, disregarding the thinly-saturated areas as insignificant. This would be similar to the original concept, but would have a significantly lower capacity, would not have a significant recharge for aid in containment, and would treat much less of the contaminant plume. Costs of this type of system would be minimal, since there could be as few as 4 to 6 dewater wells. This type of system is desirable if near-positive cutoff of contaminant is not a concern and a reduction of a significant portion of the contaminant is the major concern.

An alternative system that would provide positive cutoff would be a slurry wall system. It would be similar to the well system, with the addition of a slurry wall between the recharge and dewater well lines. Some of the concerns of a slurry wall system are:

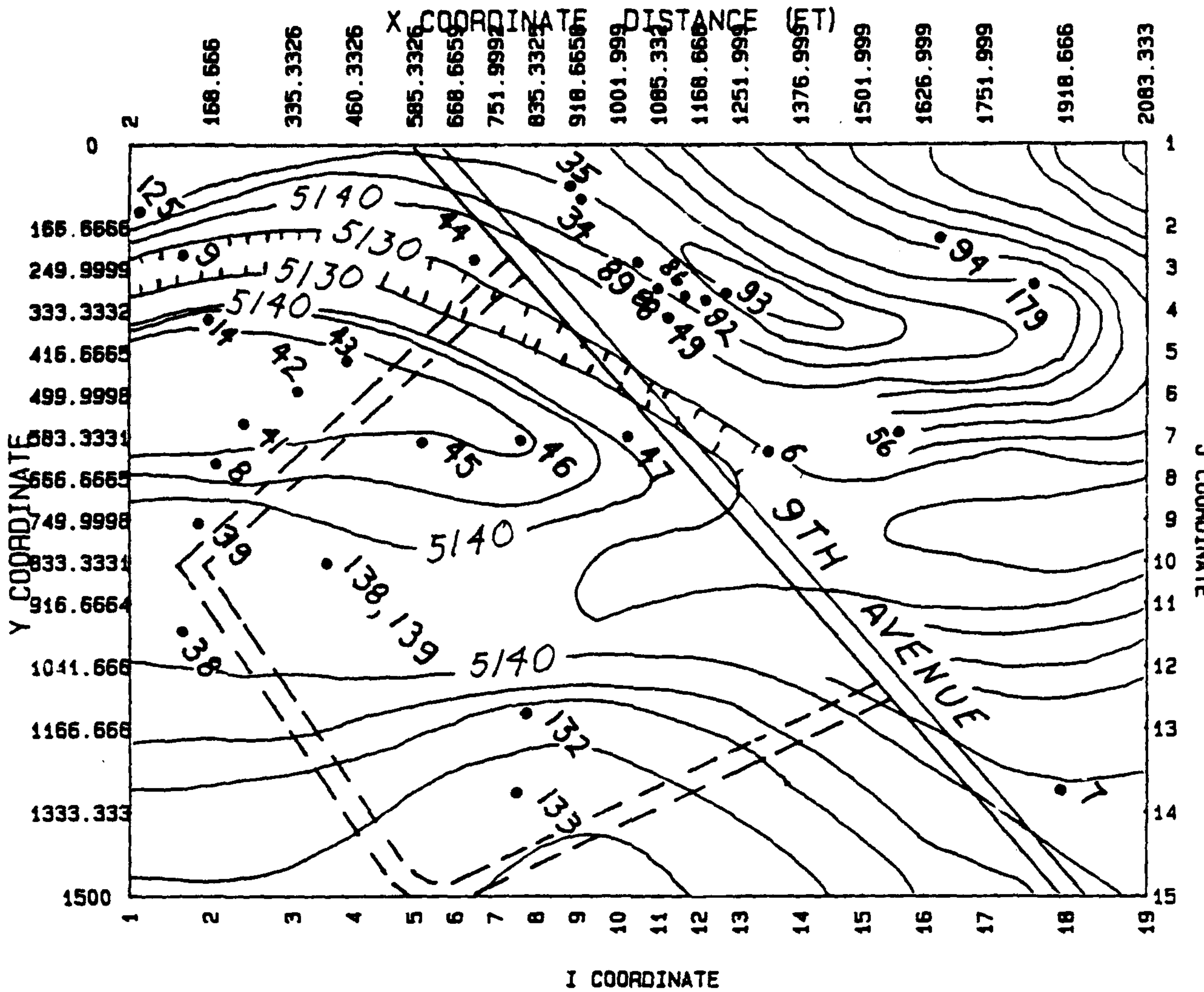
(1) The cost would be roughly equivalent to that of a well system plus the cost of a slurry wall.

(2) At depths of 40 to 60 feet to bedrock and with permeable sandstones of the Denver Formation cropping out in the project area, the lower-costing excavation methods using typical backhoes are not among the options. Heavier, more complex, and more expensive equipment would be required to excavate the slurry wall.

(3) Quality control in deep slurry walls, along with potential stability problems with such barriers when exposed to high concentrations of contaminants, makes the effectiveness of such a system questionable.

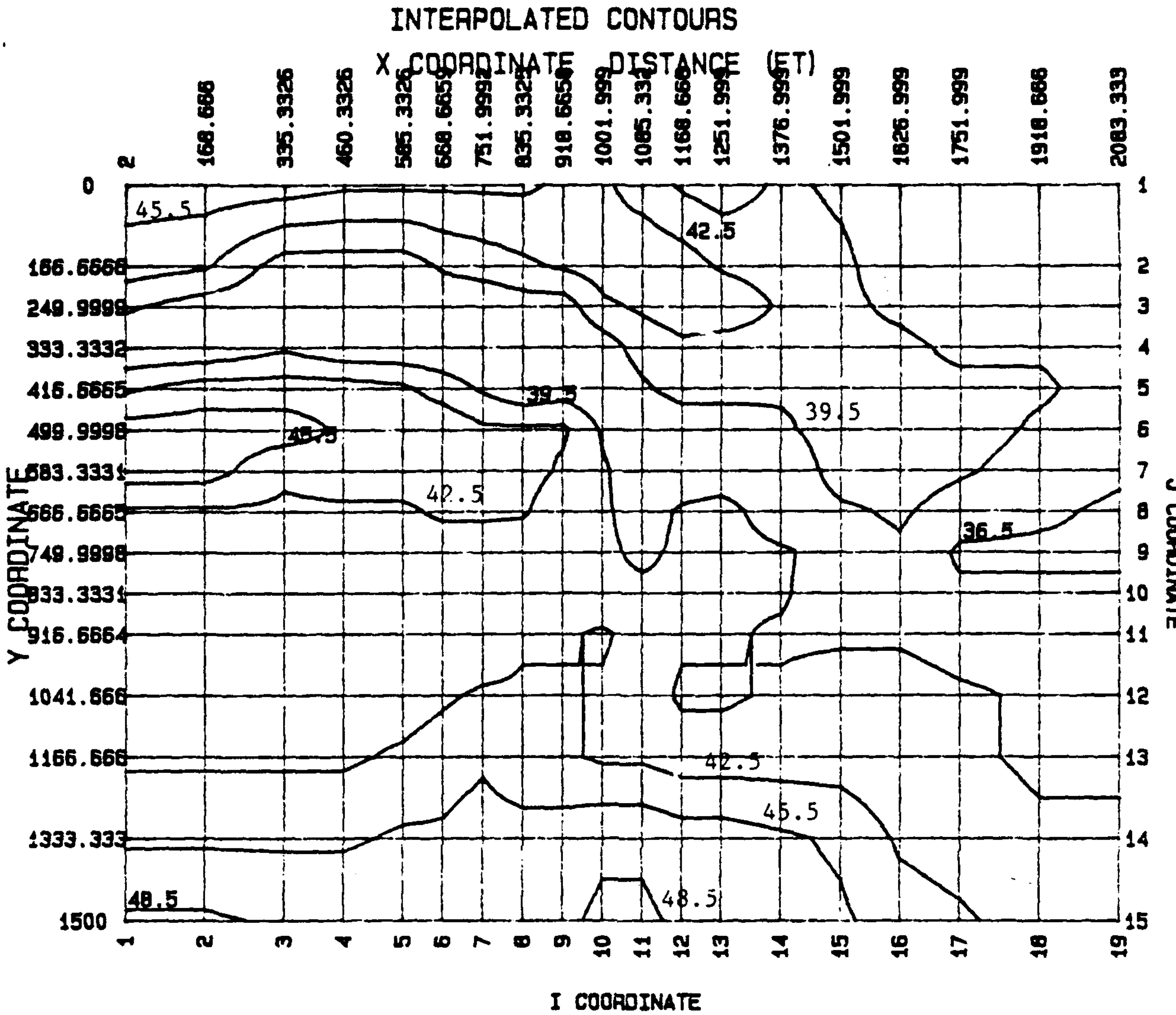
RECOMMENDATIONS: A hydrologic barrier using wells is the recommended alternative, although a range of effectiveness and effort is available within this alternative. The degree of effectiveness and effort depends upon the desired reduction in load to the North Boundary system, since a total cutoff in the interim system is prohibitively expensive and unnecessary. A well system may range from 4 wells pumping at a total system capacity of 40 gpm for a moderate contaminant reduction, to 12 wells spaced at 80-100 feet apart pumping at a total system capacity of near 180 gpm for a highly effective system.

Regardless of the degree of effectiveness determined to be necessary for the system, the seismic profile lines should be used to locate the wells for the system. The profile lines should be supplemented with 6 to 10 test borings with monitoring wells to define saturated thicknesses and contaminant levels within the bedrock channels. An additional pump test within the channels should be conducted to more accurately define the aquifer characteristics near the proposed wells.



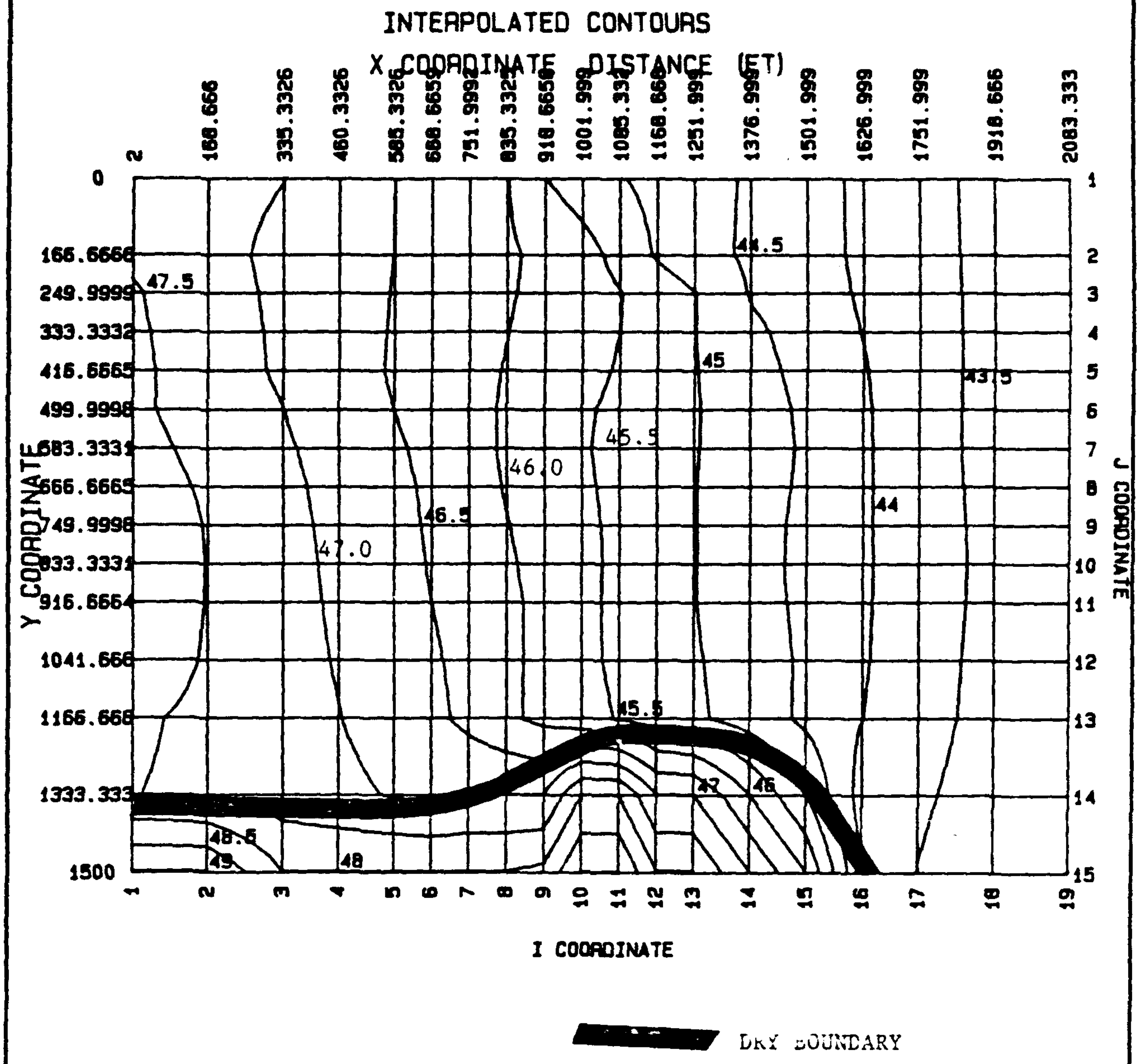
• WELL LOCATIONS

PROJECT: RMA Basin F Study FILE: RMAGRID LOCATION: Commerce City CO	STUDY AREA /W ORIGINAL BEDROCK CONTOURS
U.S. ARMY CORPS. ENGINEERS	FIGURE 1

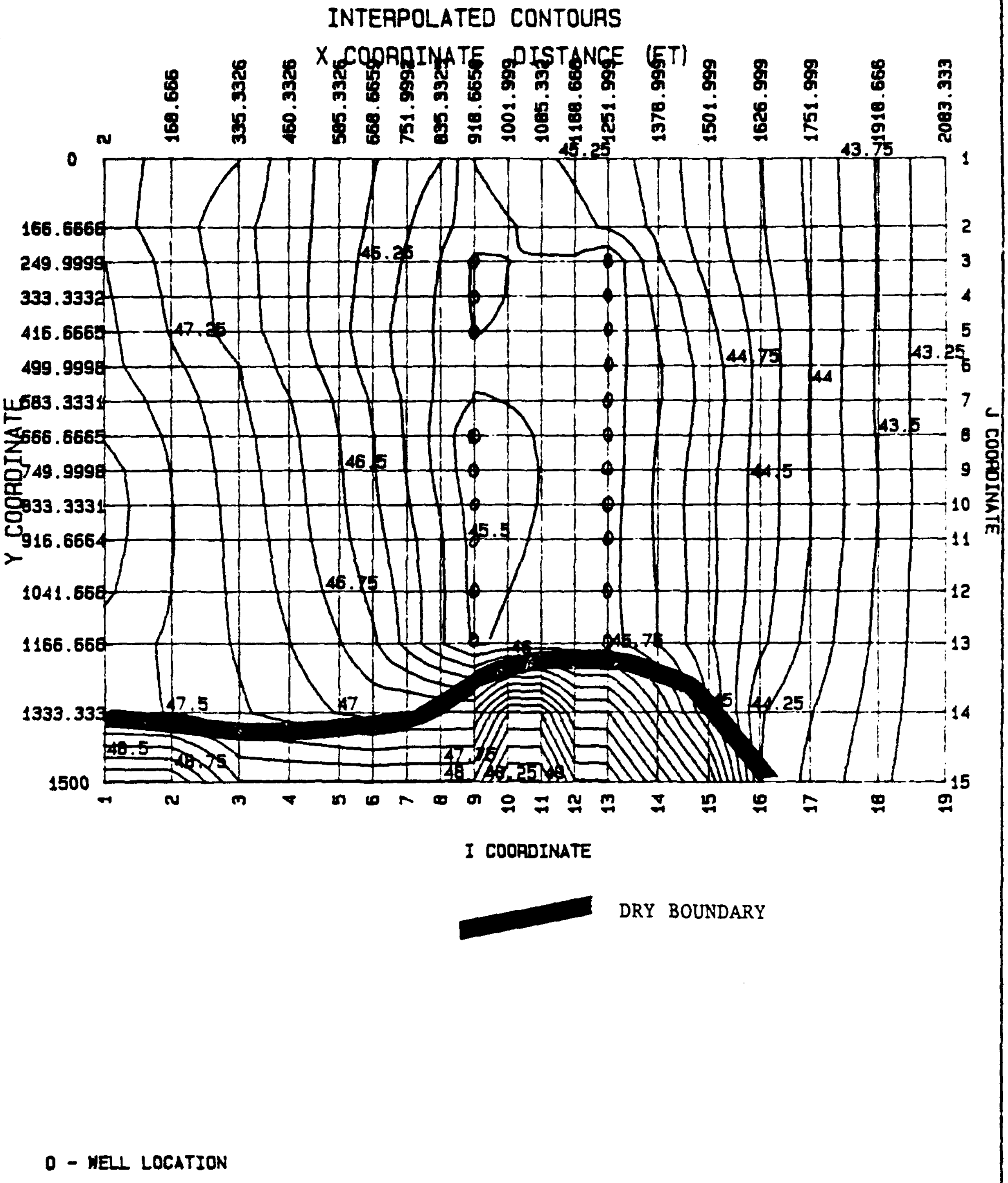


3' CONTOUR INTERVAL

PROJECT: BASIN F INTERIM FILE: RMA18 LOCATION: RMA	REVISED BEDROCK CONTOUR MAP
U.S. ARMY CORPS. ENGINEERS	FIGURE 2



PROJECT: BASIN F INTERIM FILE: RMA18 LOCATION: RMA	ORIGINAL GROUND-WATER HEAD CONTOURS
U.S. ARMY CORPS. ENGINEERS	FIGURE 3

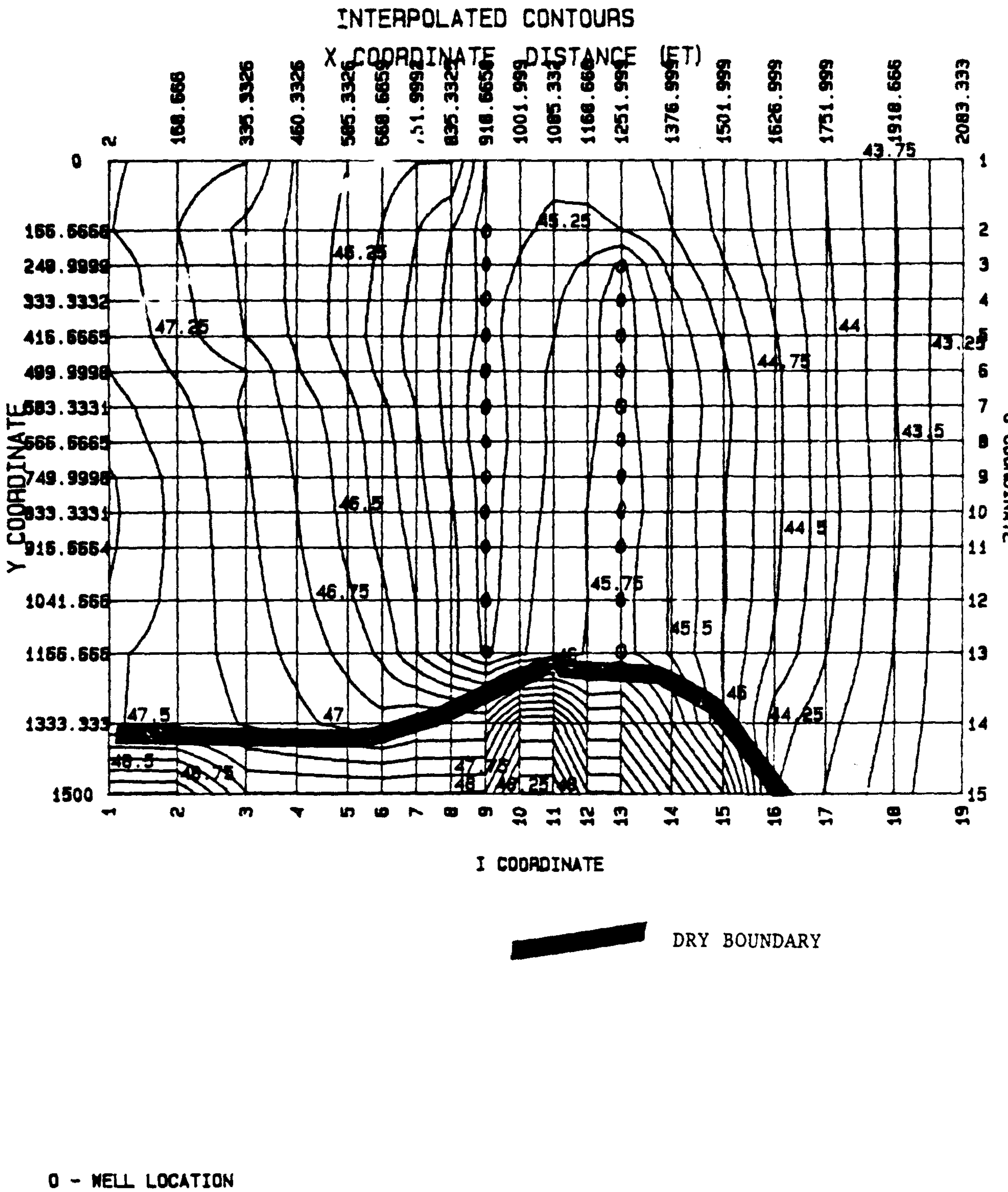


PROJECT: BASIN F INTERIM
FILE: RMA16
LOCATION: RMA

PUMPING SIMULATION @ 110 GPM

U.S. ARMY CORPS. ENGINEERS

FIGURE 4

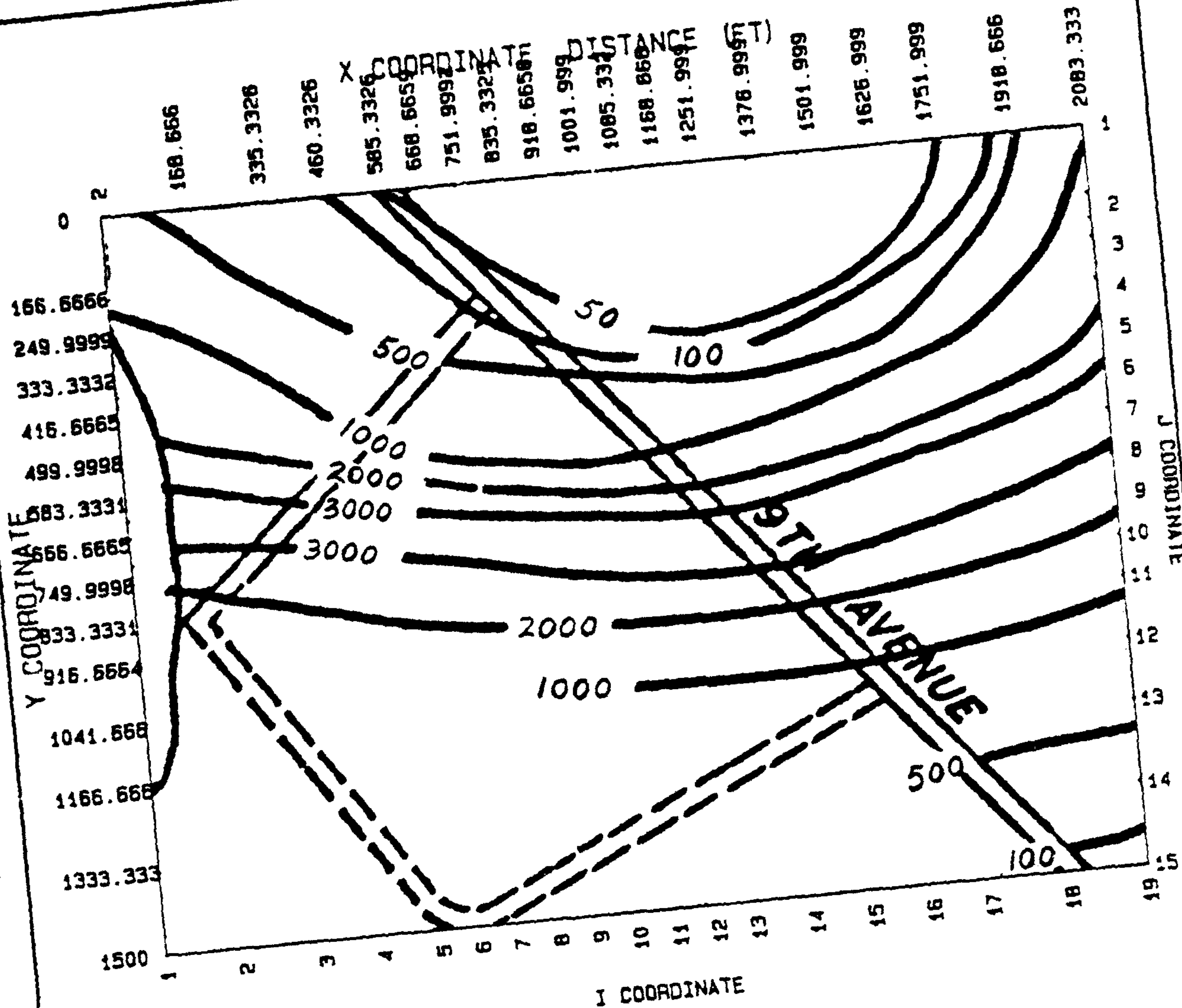


PROJECT: BASIN F INTERIM
FILE: RMA17
LOCATION: RMA

PUMPING SIMULATION @ 165 GPM

U.S. ARMY CORPS. ENGINEERS

FIGURE

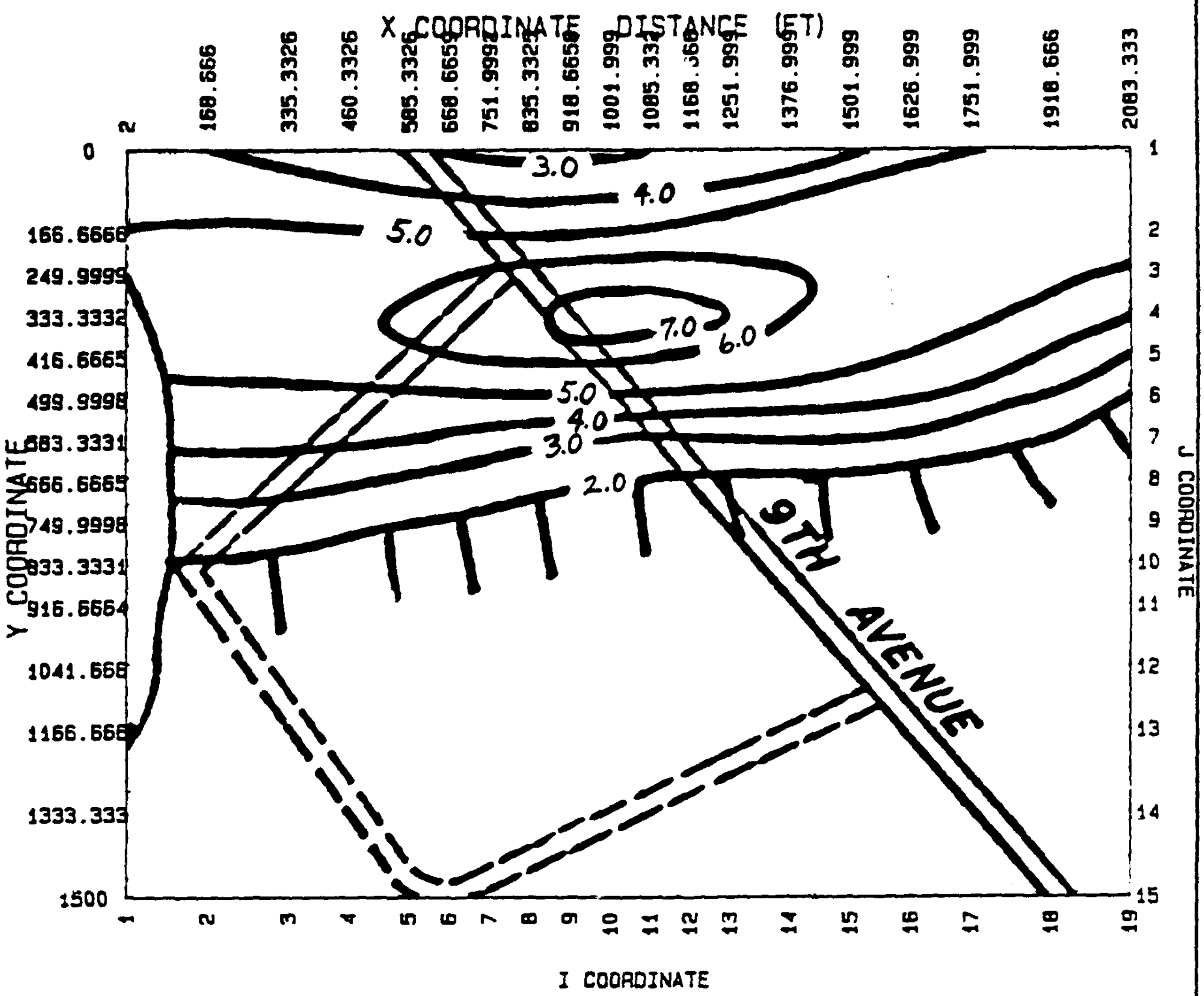


PROJECT: RMA Basin F Study
FILE: RMAGRID
LOCATION: Commerce City CO

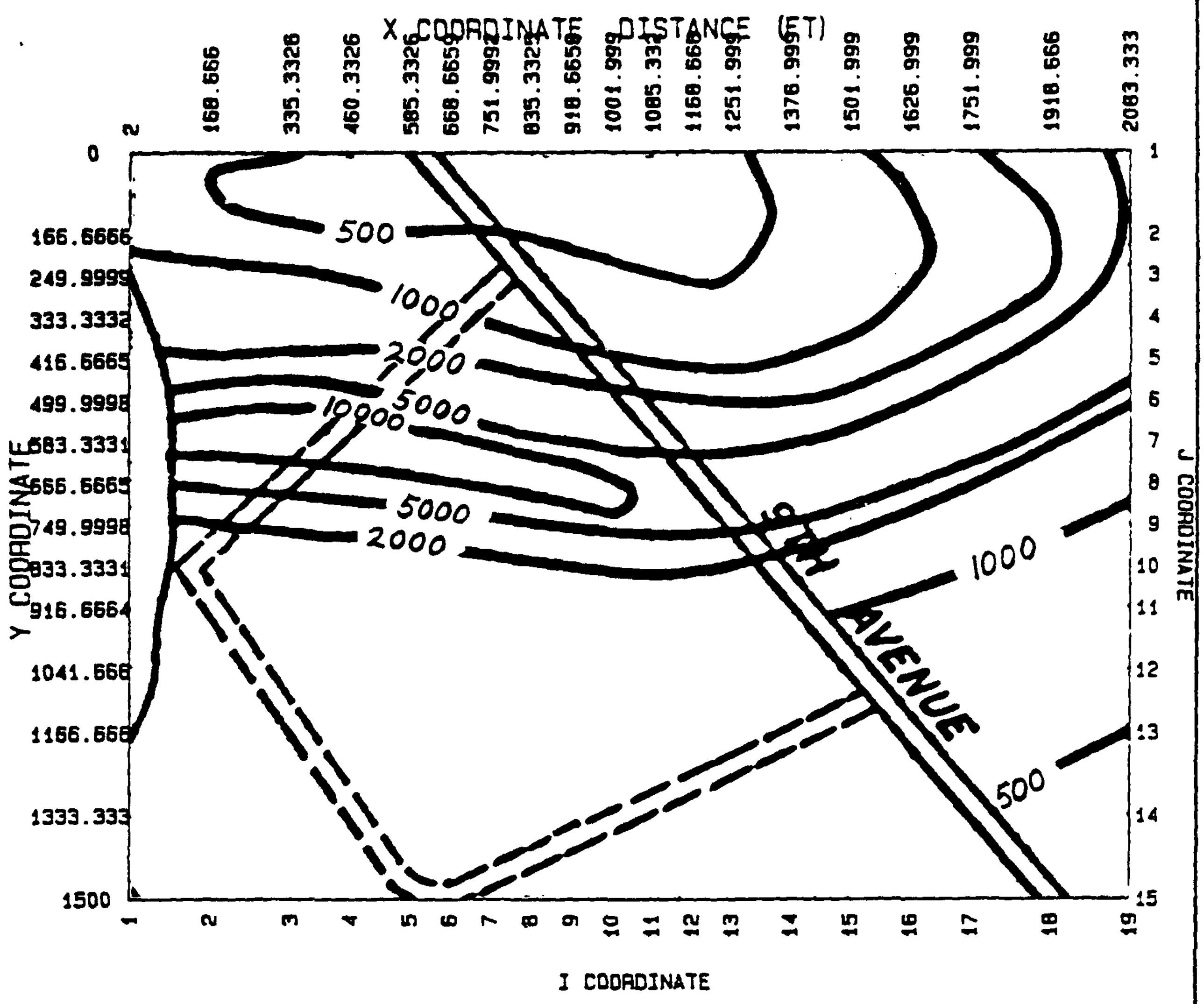
DIMP CONCENTRATIONS(PPB) 4/85

FIGURE 6

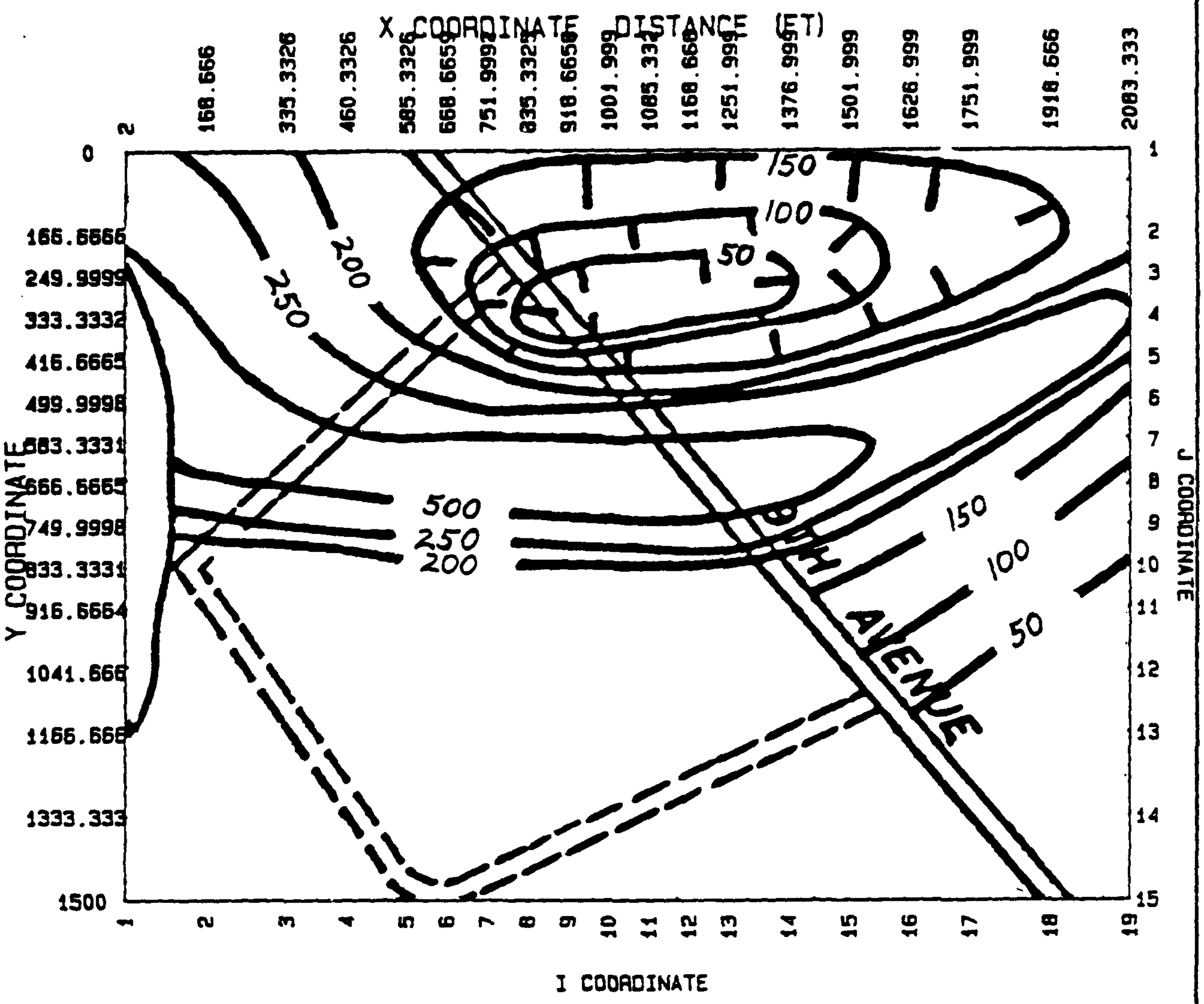
U.S. ARMY CORPS. ENGINEERS



PROJECT: RMA Basin F Study FILE: RMAGRID LOCATION: Commerce City CO	FLUORIDE CONCENTRATIONS(PPM) 4/85
U.S. ARMY CORPS. ENGINEERS	FIGURE 7



PROJECT: RMA Basin F Study FILE: RMAGRID LOCATION: Commerce City CO	CHLORIDE CONCENTRATIONS (PPM) 4/85
U.S. ARMY CORPS. ENGINEERS	FIGURE 8



PROJECT: RMA Basin F Study FILE: RMAGRID LOCATION: Commerce City CO	COMPOSITED SULFUR COMPOUND CONCENTRATIONS(PPB) 4/85
U.S. ARMY CORPS. ENGINEERS	FIGURE 9

APPENDIX A

GEOPHYSICAL SURVEY REPORT

Results from Shallow Seismic Reflection Surveys

Near

Reservoir F, Rocky Mountain Arsenal, Colorado

A Report

Prepared for

Golder Associates

By

Great Plains Geophysical, Inc.

P.O. Box 3366

Lawrence, Kansas 66045

September 1, 1987

Don W. Steeples

President

I. Introduction

This is a report prepared by Great Plains Geophysical, Inc. on contractual work performed for the Golden, Colorado office of Golder Associates. The site of the field investigaion was approximately 1/8th mile northeast of Reservoir "F" at the U.S. Army Rocky Mountain Arsenal in Denver, Colorado. The primary purpose of the project was to define the bedrock surface beneath the unconsolidated alluvial layer. The field technique used was shallow seismic reflection, which is discussed in some detail in the latter portion of this report.

The seismic reflection method has been used successfully for about 60 years in the search for petroleum. It has not been successfully used, however, for targets less than 200 feet deep until the past five years. The revolution in microelectronics has provided a new generation of engineering seismic equipment capable of recording higher frequency seismic data. The availability of higher frequencies has allowed shallower applications, particularly examination of depth to bedrock beneath alluvium.

The techniques used in the collection and processing of the seismic data displayed and discussed in this report are identical in concept to those of the petroleum exploration industry. We have simply scaled down the problem to smaller size (tens of feet instead of thousands of feet) and we have scaled up the frequency of the data to about 150-200 Hz to obtain resolution on the order of a few feet. In order to scale up the frequency, we apply 220 Hz low-cut filters to the data in the seismic amplifiers prior to analog-to-digital (A/D) conversion. We used the impact in the ground of bullets fired vertically downward from a 30.06 rifle as an energy source. Instead of using an array of geophones to sense ground motion for each channel, we use a single high frequency geophone (100 Hz natural frequency) for each recording channel.

Sections VI through VIII of this report are written as explanatory material for the reader who is not familiar with seismic reflection techniques and terminology.

II. Conclusions and Recommendations

We conclude from the seismic reflection survey that four shallow channels are present in bedrock be-

neath the area surveyed. The channels are of the order of three to six feet deep, relative to the surrounding typical bedrock elevation. The channels are roughly 60-150 feet wide. The seismic P-wave velocities within the upper few feet are less than 1100 feet per second, since the air-coupled wave from the rifle blast is the earliest wave motion on the seismograms. The average P-wave velocity between the surface and bedrock is highly variable, but averages 1450 to 1600 feet per second. The variation in velocity within the upper 50 feet is sufficient to cause processing and interpretation difficulties on these ultra shallow seismic lines.

1. OVERALL, WE CONCLUDE THAT THE SEISMIC REFLECTION LINES PROVIDE IMPORTANT NEW INFORMATION ABOUT THE BEDROCK SURFACE CONFIGURATION AT THE SITE. THIS INFORMATION IS DEPICTED AS CROSS SECTIONS IN FIGURES 2, 3, AND 4 AND AS A BEDROCK CONTOUR MAP ON FIGURE 5. THE MOST SIGNIFICANT POINT OF THIS REPORT IS THAT OUR INTERPRETATION SUGGESTS BEDROCK CHANNELS IN THE SEISMIC SURVEY AREA TREND NORTHWESTWARD INSTEAD OF NORTHEASTWARD AS PREVIOUSLY INTERPRETED FROM DRILLING DATA. ANY SUBSEQUENT DRILLING SHOULD BE PLANNED USING TABLE 1 ON PAGE 17 OF THIS REPORT.

2. THE SEISMIC P-WAVE VELOCITIES IN THE NEAR-SURFACE SOIL AND ALLUVIUM ARE VERY SLOW, AVERAGING NO MORE THAN 1600 FEET PER SECOND. THE P-WAVE VELOCITY WITHIN THE UPPER FEW FEET IS HIGHLY VARIABLE IN THE AREA, BUT IS LESS THAN 1100 FEET/SECOND, POSSIBLY AS LOW AS 800 FEET/SECOND.

3. IF FURTHER DEFINITION ON THE TOP OF THE BEDROCK IS NEEDED, ADDITIONAL SEISMIC LINES WOULD BE USEFUL. IN PARTICULAR, EXTENSION OF LINE B TO THE NORTHWEST WOULD ALLOW BETTER DEFINITION OF THE BEDROCK CHANNEL NOTED AT THE NORTHWEST END OF LINE A. WE BELIEVE THAT PARTICULAR CHANNEL COULD BE IMPORTANT IN ANY FLOW PATTERN ALONG THE BEDROCK/ALLUVIAL INTERFACE. WE WOULD ALSO RECOMMEND USE OF AT LEAST ONE TIE LINE TO CONNECT THE OTHER LINES TOGETHER. THIS WOULD ELIMINATE SO-CALLED STATIC SHIFTS IN INTERPRETED DEPTH TO BEDROCK CAUSED BY VELOCITY VARIATIONS THAT RESULT IN REFLECTION TRAVEL TIME VARIATIONS FROM ONE LINE TO ANOTHER.

4. THE NOISE FROM AIRCRAFT TAKING OFF FROM DENVER'S STAPLETON AIRPORT DEGRADES DATA QUALITY ON SOME FIELD FILES. AN EXAMPLE OF THIS

NOISE IS SHOWN AS FIGURE 6. ANY FURTHER SEISMIC WORK SHOULD ALLOW ABOUT 10% EXTRA FIELD TIME TO AVOID TAKING DATA DURING TIMES OF LOUD AIRPLANE NOISE. EXTRA EFFORT AND CARE WAS NEEDED DURING PROCESSING TO DECREASE THE DELETERIOUS EFFECTS OF THIS NOISE.

III. Seismic Section Interpretation

A map location of the seismic lines is shown in Figure 1. The seismic data quality on the lines varies from poor to excellent. The heterogeneous nature of the alluvial material and the presence of roads and airplane noise caused this variation.

The cross-sectional interpretation of each seismic line is shown immediately above the seismic sections. After the lines were individually interpreted, correlating bedrock channels from line-to-line allowed development of an interpretive bedrock contour map (Figure 5). Individual bedrock channels were correlated between lines by overlaying seismic sections and interpretations on a light table. Channel morphology (both size and wall shape) was surprisingly consistent from one line to another and proved to be a useful tool in the interpretation.

As noted earlier in this report, the bedrock channels are interpreted here to trend northwestward rather than northeastward as previously interpreted from drilling data. In particular the channel near the northwest end of line A is not similar in size or shape to any other channel and appears to be both bigger and deeper than any other channel. The fact that this channel does not appear on either line B or line C played a big role in our overall interpretation.

Line A Discussion

As shown on Figure 2, this line shows two shallow bedrock channels roughly 100 feet wide. The data quality of the processed section is generally excellent except between CDP locations 1240 and 1260 where the line crossed an old trail and between CDP locations 1360 and 1390 where both a road and decreased CDP fold associated with the end of the line degrade the data quality. The bedrock channels extend from about CDP 1150 to CDP 1207 (114 feet wide, at least 4 feet deep) and from CDP 1315 to (questionably) CDP 1390 (150 feet wide and at least 6 feet deep). It would be useful for this line to be extended northwestward to better define the northwestern extent of the bedrock channel. It would

also be helpful if line B were extended northwestward to determine the directional trend of this channel.

Line B Discussion

The data quality on this line is not as good as on lines A and C. The southeastern-most channel appears to start at CDP 642 and extend to CDP 692, a distance of 100 feet, and it is at least 4 feet deep. This channel is interpreted in a area of the stacked seismic section that possesses many static and/or velocity inconsistencies. The northwestern-most channel starts at CDP 875 and extends to CDP 935, a distance of 120 feet, and it is at least 4 feet deep. The reflector interpreted on line B lacks the strong coherency (and high quality) present on most of lines A and C.

Line C Discussion

The bedrock channels on line C extend from CDP location 318 to 370 (104 feet wide, at least 4 feet deep) and from CDP location 420 to 450 (60 feet wide, at least 4 feet deep) respectively. Data quality is excellent except between CDP locations 260 and 280 where the seismic line crosses a road.

IV. Discussion of Data

This section is written to provide technical specifications about field recording and data processing for other geophysicists who might read this report. Line C was recorded off-end with minimum offset of 8 feet. Lines B and C were shot split-spread dropping 5 takeouts so source-to-closest-receiver distance was 10 feet. All recording was done with single undamped 100 Hz Mark Products L-40 geophones. Geophone spacing was 2 feet on line C and 4 feet on lines A and B. Recording was done on an Input/Output DHR 2400 seismograph with 24 fixed-gain (i.e. not floating point) amplifiers. Lo-cut filters were at 220 Hz (-3dB point, 24 dB per octave). Sample interval was 1/4 msec with record length of 1/8 second. All lines employed a 30.06 rifle as a seismic source. Single shots were fired downward at each shotpoint with the tip of the barrel placed about 5" below the ground surface. Shotpoints were four feet apart on all lines.

Data processing was done on a Data General MV/20000 computer using standard CDP processing algorithms from Sytech, Inc. Processing flow included scaling (automatic gain control), CDP sort, elevation static correction, surface consistent static correc-

tions, velocity analysis, digital filtering, NMO correction, and deconvolution. Since the bedrock surface was the primary reflection objective a second-zero-crossing auto-predictive deconvolution was used to increase the frequency and to partially suppress the ringy source wavelet. It is not necessary to completely remove ringyness of the source wavelet to define a single surface such as bedrock.

For the purpose of showing quality of some of the best field data, an unprocessed field record is plotted on Figure 7. The field record shows excellent indication of bedrock reflections.

The weather conditions during record collection were generally good with warm temperatures and light winds. The surface conditions were adequate, though variable, except in the vicinity of roads. Overall, the field and weather conditions were good. Noise from Stapleton Airport degraded data quality somewhat.

V. Accuracy and Precision of Data

It is possible to time the arrivals of the reflectors on the seismic sections to the nearest millisecond. Since one millisecond of difference in reflection

time corresponds to about two feet in two-way distance in the alluvium, we establish our precision at two feet. This is larger than the precision of the elevation data from the topographic survey which was done to 0.1 foot. The topographic data are attached at the end of the report.

Our absolute accuracy, on the other hand, is not nearly so well defined. The seismic P-wave velocity in the unsaturated alluvium is highly variable, from as low as 800 feet per second to as high as 2000 feet per second. In the bedrock valleys where the alluvium is water-saturated, the seismic velocities may increase to 3000 to 4000 feet per second. Without an uphole velocity check-shot survey, it is not possible for us to observe or calculate the correct velocity below the water table. As a result, the estimated depths to the bottoms of the bedrock channels are probably minimum depth estimates. There are also hints of low velocity layers in the alluvium, which is another source of possible error in estimating depth.

The velocity is highly dependent upon clay content, moisture content, and the degree of compaction. In general, our velocity analysis provides velocity determination to within 10% to 15% of true velocity

above bedrock. Hence, our absolute errors in depth to bedrock can range as high as 15%, or approximately 7 feet along most of the lines.

Our relative absolute errors along individual lines should be less than 4 feet except where roads are present. In other words, where the data are tied by absolute measurement to a borehole, the relative error along a seismic line should be less than 4 feet, provided drastic changes in alluvial composition do not occur laterally.

The possibility of substantial changes in alluvial composition and/or age arises from our observation that the average reflection time of the bedrock reflector is about 3 msec greater on line A than on line C. This implies that either the bedrock is on average deeper on line A than line C, or that there are at least two or three feet of additional very-low velocity material present near the the surface on line A than line C. The topographic elevation is two to four feet higher for line A than for line C, so it is reasonable to expect a couple of feet of additional low-velocity material on line A. We believe the near-surface low-velocity material is the likely explanation in view of the borehole data in the area, and we have made our inter-

pretations based on that assumption. After a review of all of the borehole data in the area we believe a southerly dip of the alluvial/bedrock interface is unlikely but not impossible.

VI. Field Techniques

Physically in the field, geophones with 6 inch long spikes were emplaced along the seismic profiles at 4 foot intervals on lines A and B and at 2 foot intervals on line C. The geophones transmitted their signals to the seismic recording truck via multichannel seismic cable. The data were amplified and filtered in the recording truck, converted to digital form, and placed on computer tape for later processing in a large computation facility.

The seismograph used in gathering data for this report has 24 channels, allowing the use of a technique known as the Common Depth Point (CDP) method. As the survey progressed along the line of the seismic profile, shots were fired at the same spatial interval that was used for geophone emplacements except on line C where a shot was fired at alternate geophone locations. The reason for the CDP terminology can be noted in Figures 8 and 9. Figure 8 shows schematic ray paths

for a single shot recorded by a multichannel seismograph.

Figure 9 demonstrates the concept of the common midpoint between shotpoints and geophones. Using ray theory and flat geologic layers there is a point on a seismic reflector that is midway between both Shotpoint 1 and Geophone 2 and between Shotpoint 2 and Geophone 1. This common midpoint is also commonly referred to as a Common Depth Point, hence the abbreviation CDP. In case of a 24 channel seismograph with a shotpoint and geophone interval of the same number of feet, each CDP location is sampled 12 times during the course of the survey. Hence, this report contains data with 12 fold CDP redundancy. Although we do not graphically portray it in this report, the resulting subsurface CDP locations are only one half shotpoint interval apart, so that a 400 foot long seismic line with 100 shotpoints four feet apart results in 200 CDP points two feet apart.

VII. Data Processing and Display

Each CDP location in the above discussion will

have 12 seismic traces unique to it. The seismic data are then processed so that the 12 traces are added together in a coherent and geometrically correct fashion. The resulting plotted profile is generally much easier to interpret and is more reliable than seismic data involving only one seismic trace. In order to make the geometrical correction prior to summing the seismic traces, the analyst must determine the velocity of the seismic waves in various layers. This is a very important part of the data processing and is done largely by trial and error for shallow seismic applications.

A seismic record section such as displayed in this report may be thought of as a "pseudo-road cut". In other words, there are places along most highways were excavation through hills has exposed layers of rock. It is possible to look at the rock units in cross-section at such road cut localities. A seismic record section is a display of the acoustic properties of the geologic cross-section in much the same manner as a road cut displays rock layers. This concept is shown schematically in Figure 10. In the case of this report, the "pseudo-road cut" display is several hundred feet long and no more than a hundred feet deep.

VIII. Data Interpretation Technique

Interpretation of the seismic sections then becomes a matter of tracing coherent waveforms on the seismic sections. Each coherent set of waveforms corresponds to some acoustical layer in the subsurface, most commonly a change in rock type. In the case of this report, the bedrock reflection has one prominent peak and two smaller peaks, rather than a single peak. This is referred to commonly as a "ringy" wavelet. This can be caused either by the relatively severe locut filters or by the highly attenuative low velocity near-surface layer, or both.

The source wavelet generated by a rifle bullet is similar in shape to that shown in Figure 11, provided the near-surface has low attenuation. The bedrock reflection on the seismic record sections manifests itself as two positive blackened peaks sandwiching a negative trough that is not blackened, or as three blackened peaks sandwiching two negative troughs depending upon near-surface conditions. In calculating depth to bedrock, it is most correct to compare times of the onset on the upper blackened peak. While additional deconvolution efforts could decrease the peaks from

three to two or even to one, there is little to be gained from the effort and expense of that exercise, since the wavelet ringyness has no effect on the interpretation of depth to bedrock. While suppression of the wavelet ring could be done by use of spiking deconvolution, it might be at the expense of losing some low amplitude, low signal-to-noise ratio reflections that are useful in the interpretation.

Table 1*

Locations of bedrock channels relative to seismic lines. All distances in feet from southeast end of surveyed lines. Note on Figure 5 that there are two channels on each line, but that there are a total of four channels within the area of Figure 5. No individual channel intersects all three lines.

Line	Southeastern Channel			Northwestern Channel		
	SE Edge	Deepest Part	NW Edge	SE Edge	Deepest Part	NW Edge
A	300	352	414	630	724	780
B	84	120	184	550	590	670
C	236	310	340	440	472	500

*This table should be used in planning any subsequent drilling. The maps should <u>not</u> be used because of minor inaccuracies in plotting the locations of seismic lines on the maps that were supplied to Great Plains Geophysical, Inc.

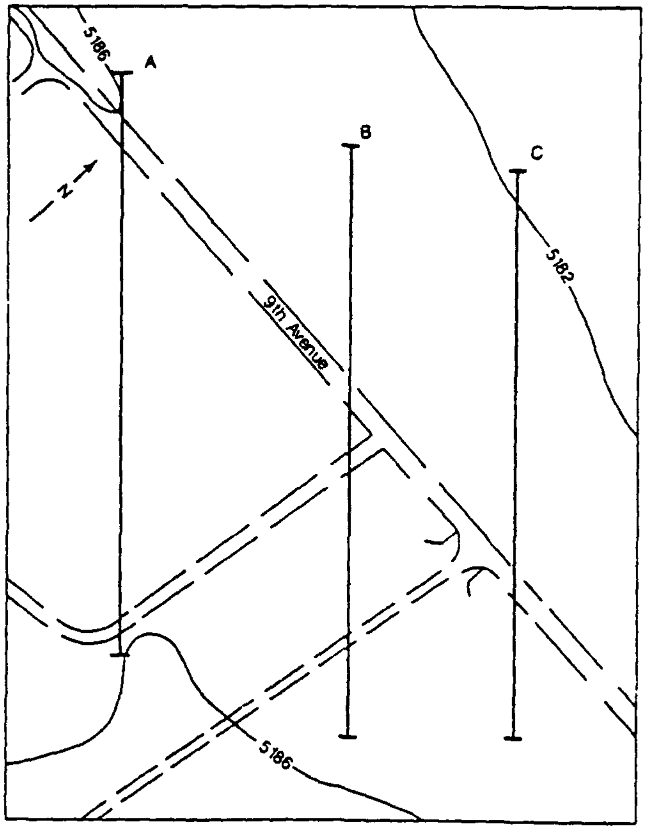


Figure 1. Base map showing surface topography and location of seismic lines relative to roads in the vicinity of the study area. (Note that the road and line locations and lengths are only approximate due to inaccuracies in the seismic line map provided to us. Any new drill sites should be chosen on the basis of Table 1 rather than from the maps of this report.)

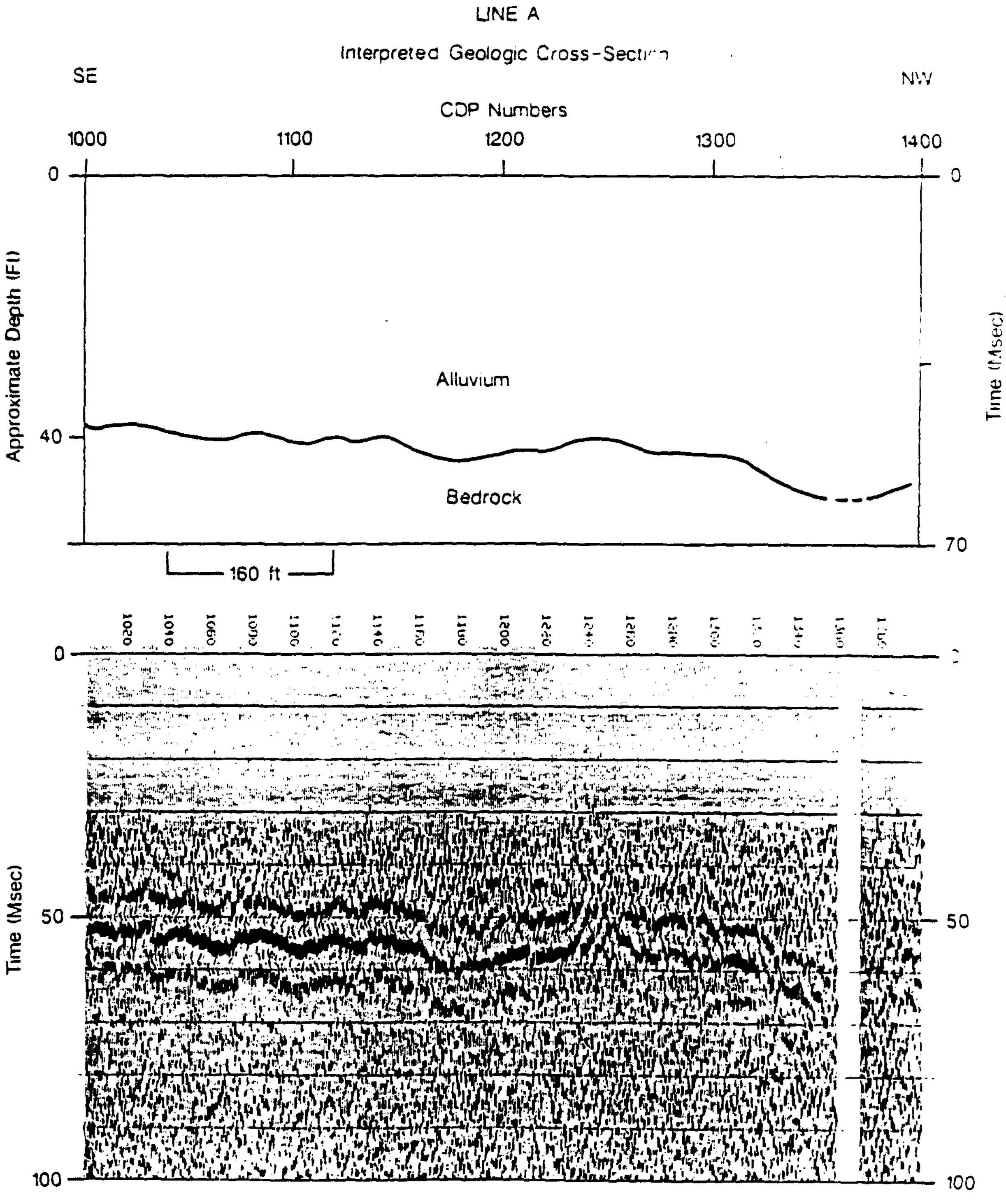


Figure 2. Seismic section and geologic cross-section of Line A. Each CDP trace is separated by 2 feet and possesses at least 6 fold and as much as 12 fold redundancy. The geologic cross-section clearly defines the alluvial/bedrock interface.

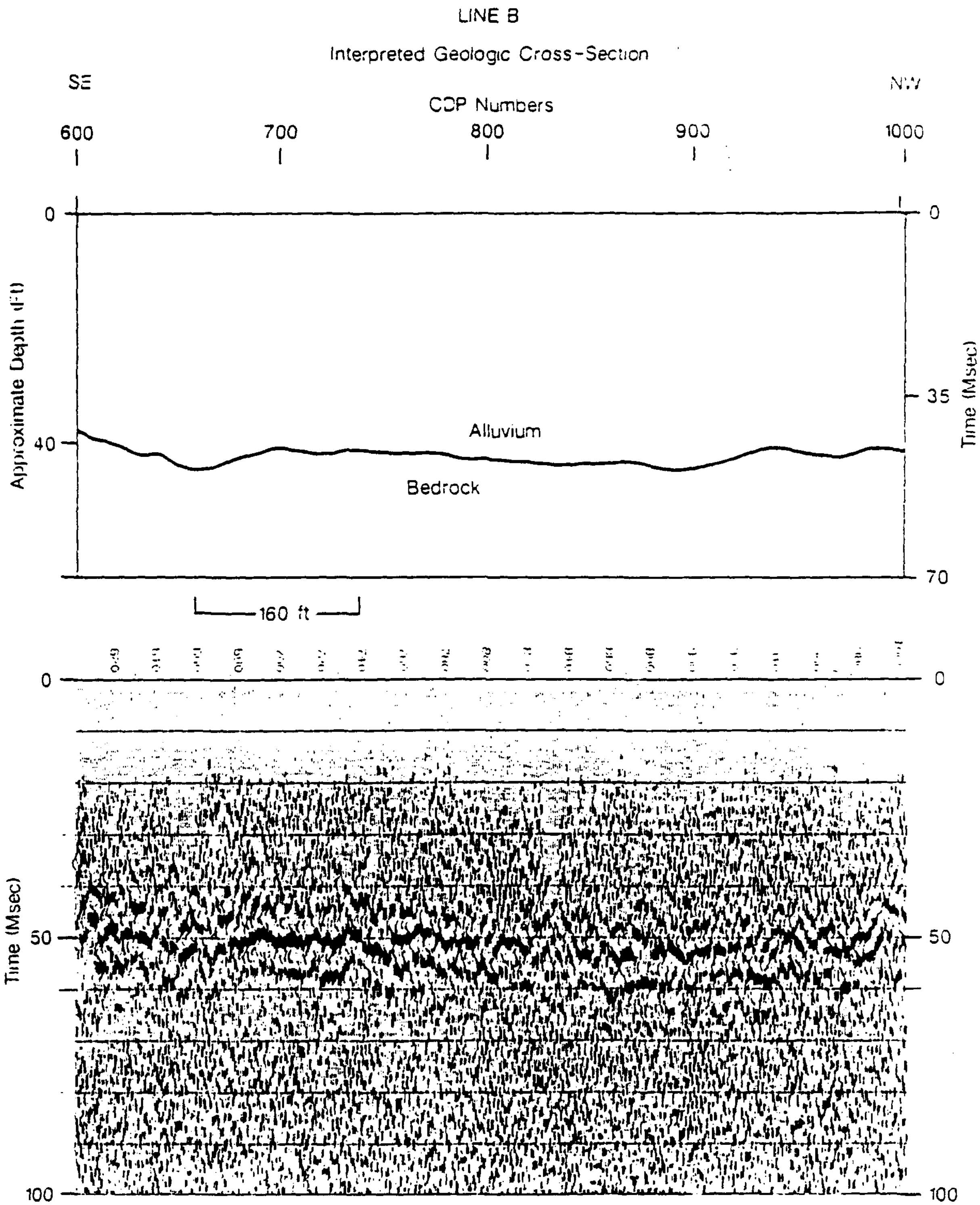


Figure 3. Seismic section and geologic cross-section of Line B. Each CDP trace is separated by 2 feet and possesses at least 6 fold and as much as 12 fold redundancy. The poor coherency in the bedrock reflection wavelet from trace to trace could be a result of the multiple roads and trails crossed during the acquisition of Line B.

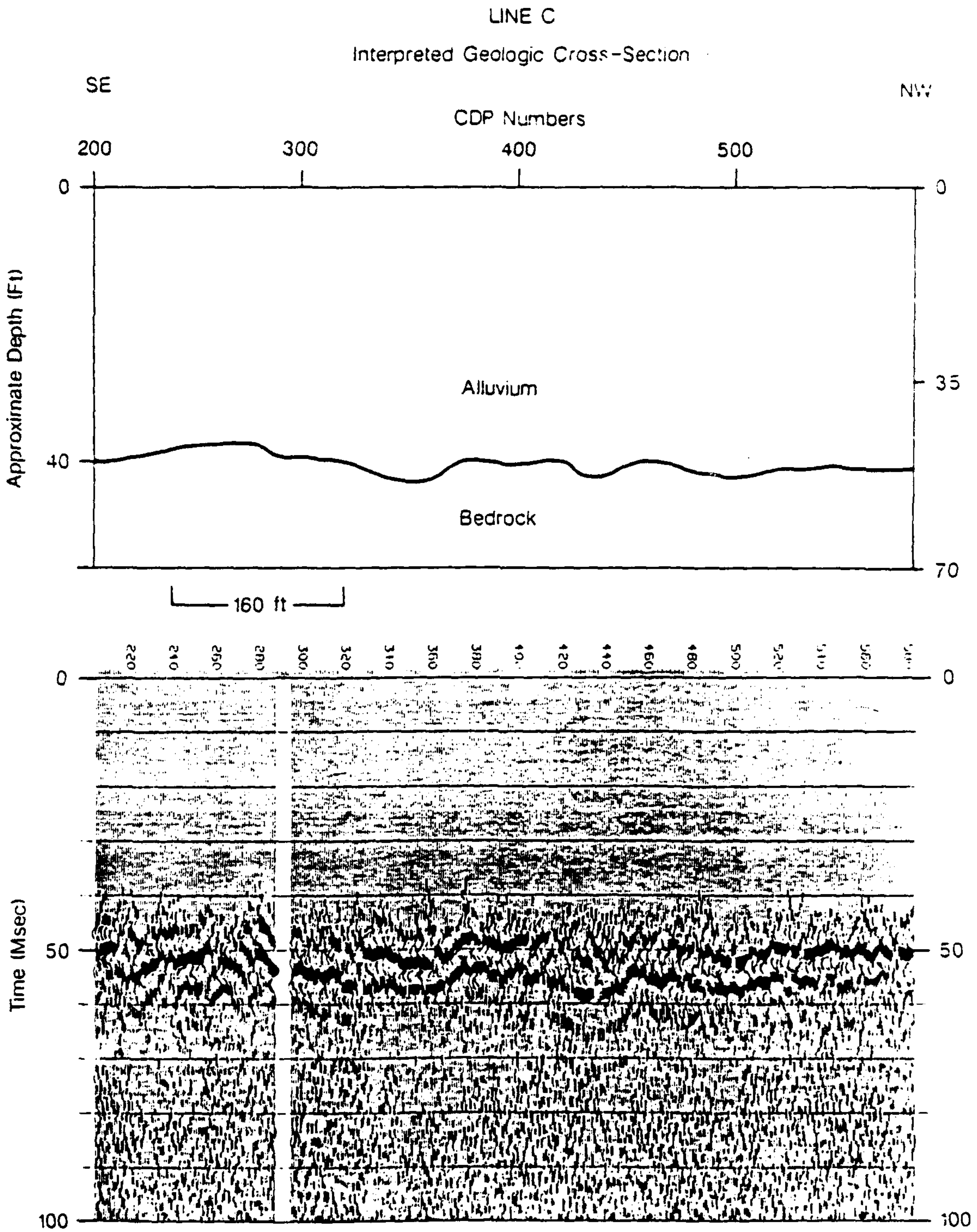


Figure 4. Seismic section and geologic cross-section of Line C. Each CDP trace is separated by 2 feet and possesses at least 6 fold and as much as 12 fold redundancy. The geologic cross-section clearly defines the alluvial/bedrock interface.

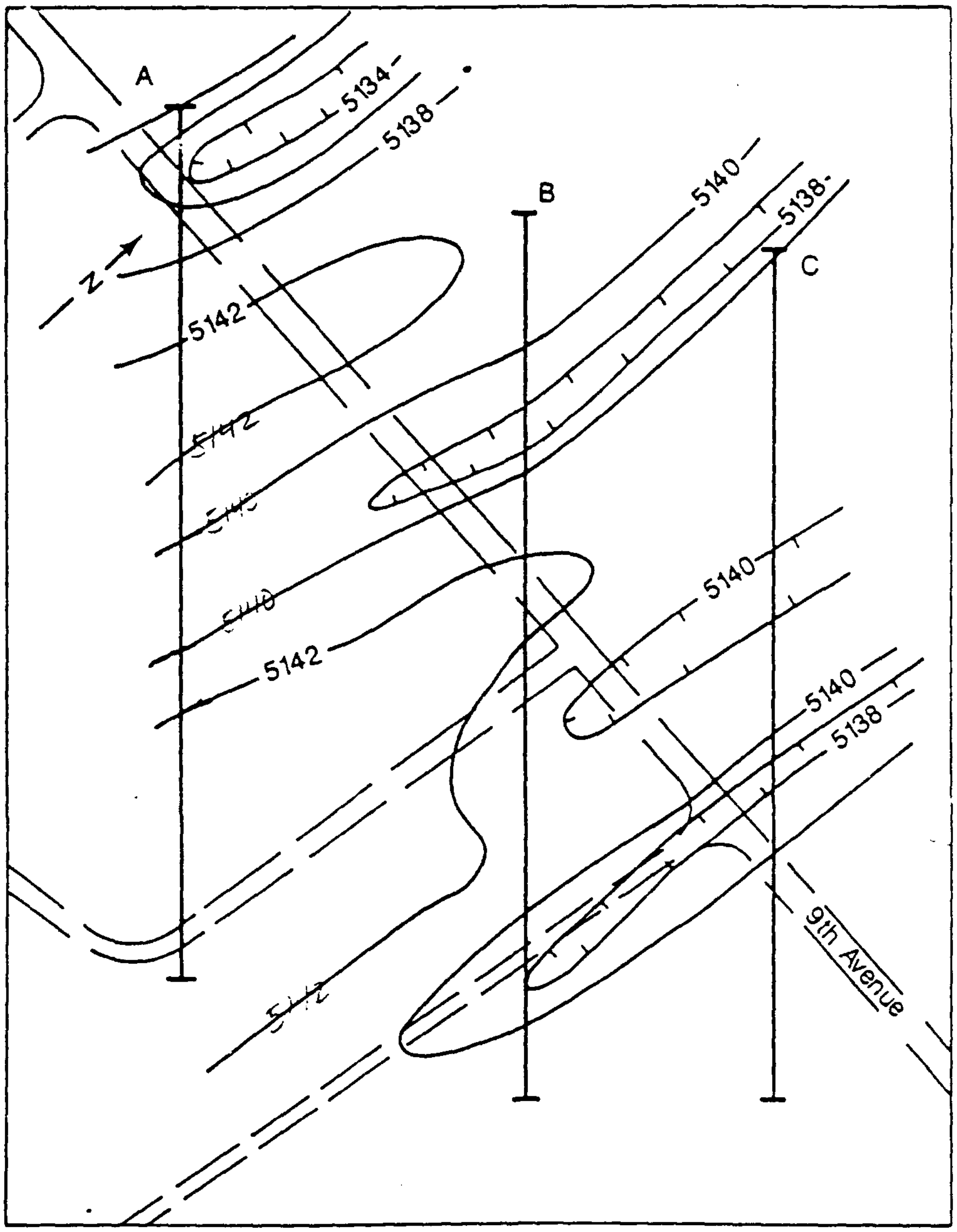


Figure 5. Bedrock contour map of area within seismic survey. Note bedrock valleys trend generally northwestward.

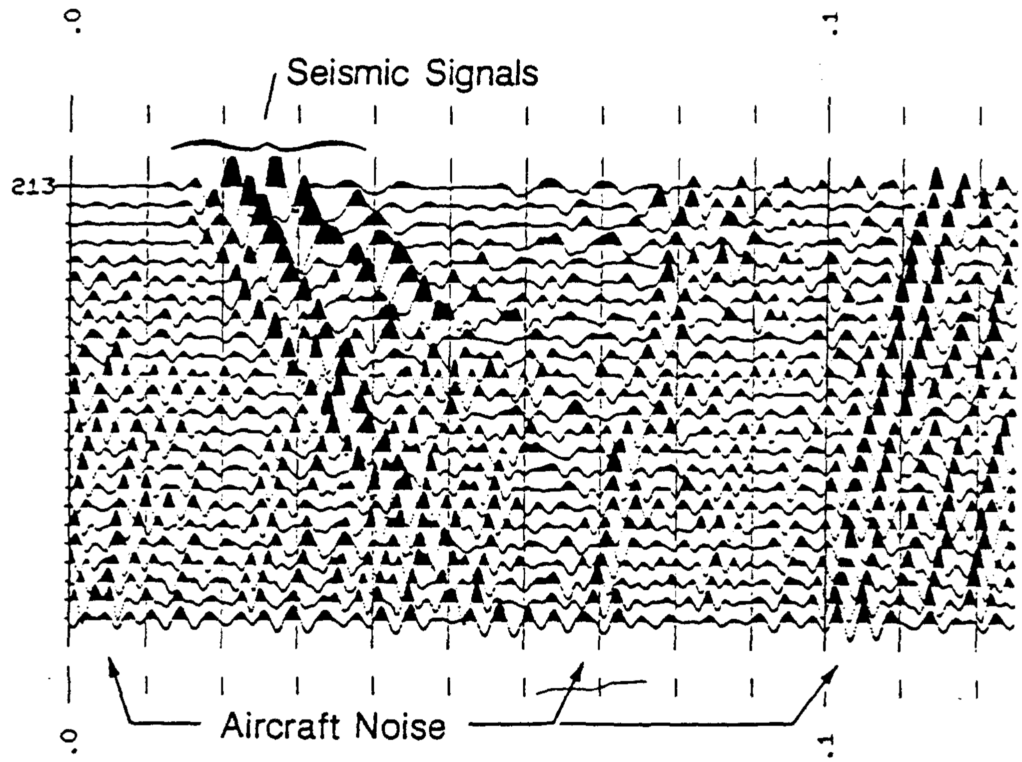


Figure 6. Unprocessed field seismogram showing noise from jet aircraft taking off. Noise highlighted by arrows.

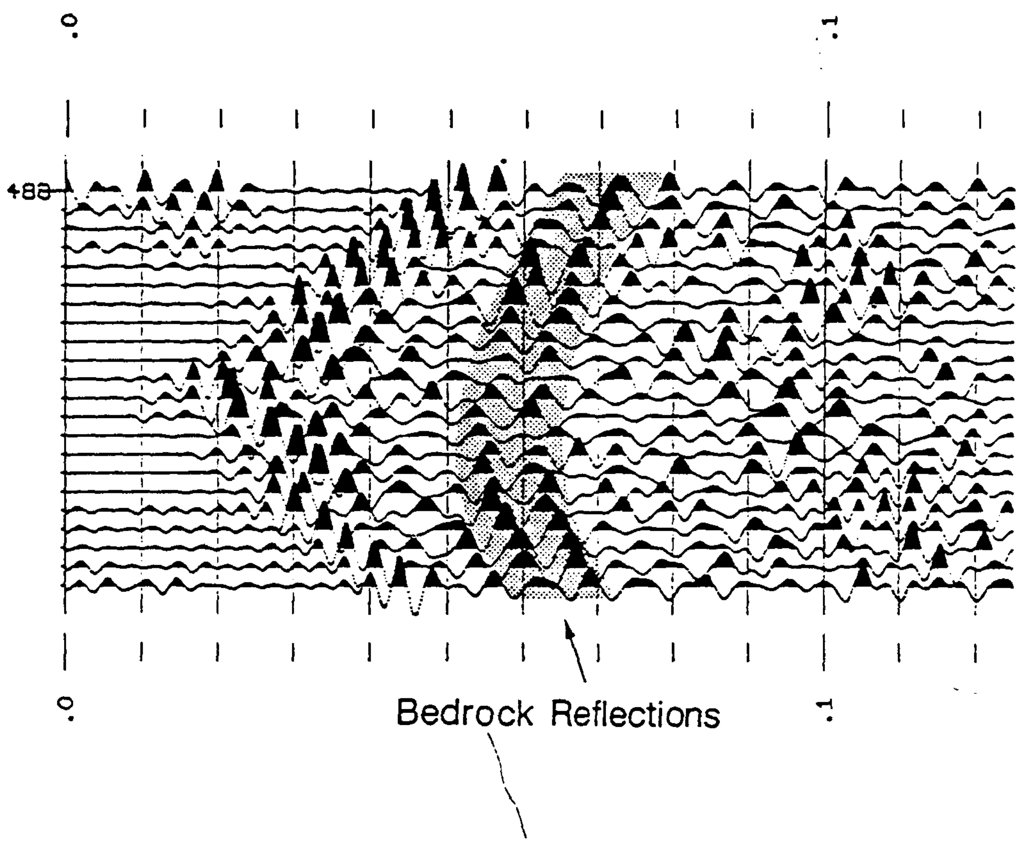


Figure 7. Unprocessed field data showing bedrock reflector. Reflector is within the shaded area between times of 50 and 70 milliseconds.

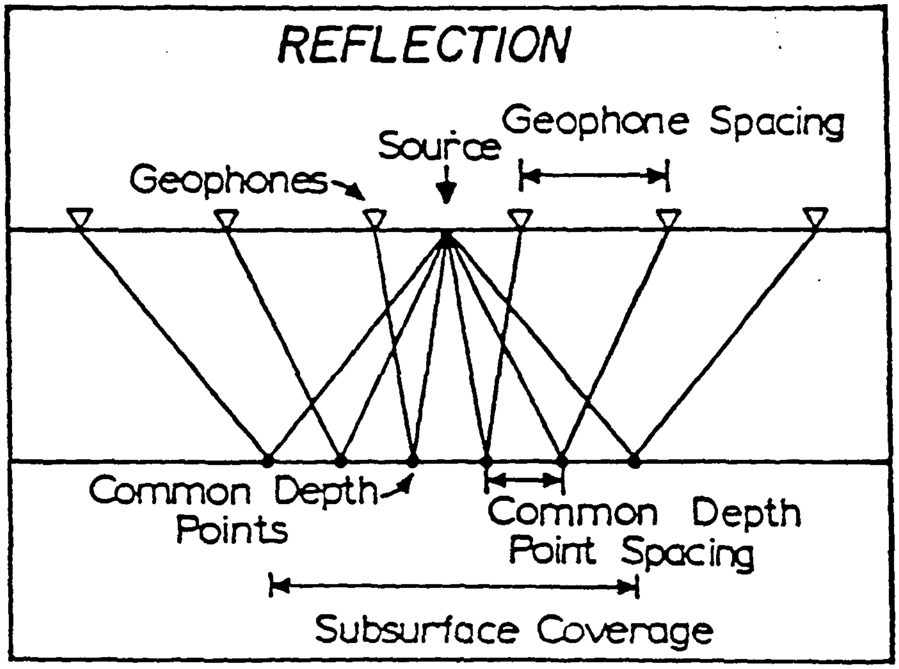


Figure 8. Schematic drawing of seismic ray paths for a single shot with a six-channel reflection seismograph. Note that the CDP spacing in the subsurface is half the geophone spacing at the surface.

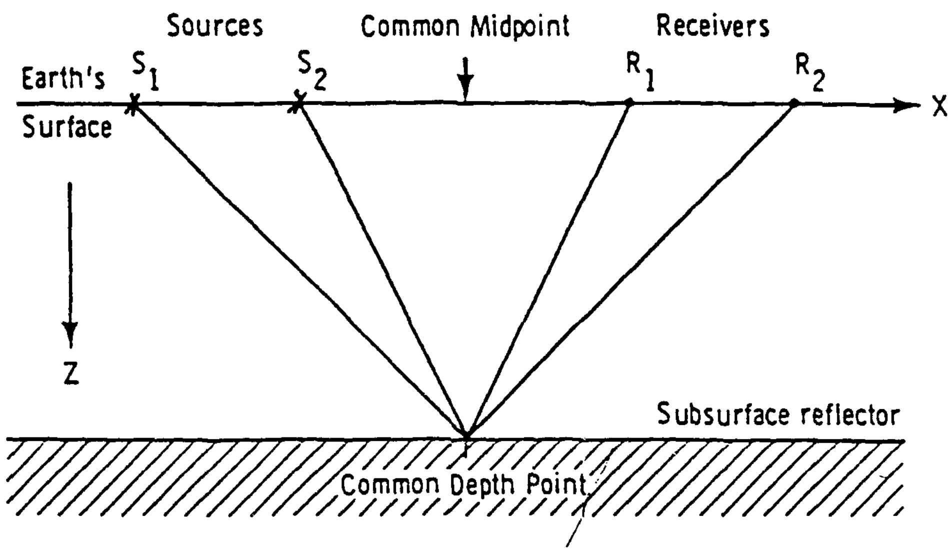


Figure 9. The concept of Common Depth Point (CDP). Note that ray paths from two different shots (S_1 and S_2) reflect from a common point in the subsurface.

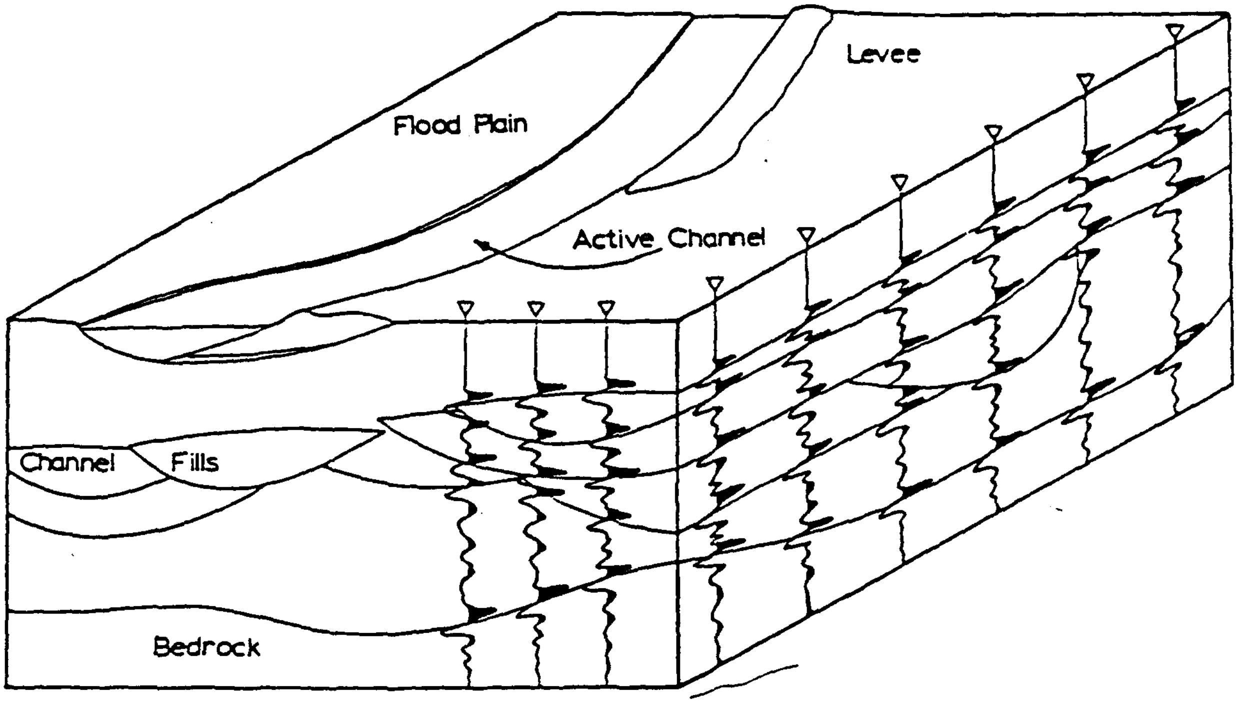


Figure 10. Schematic diagram of how a seismic section relates to real-world geology. In the case of this report, the only strong reflector is the bedrock reflector which shows up as a triple black peak.

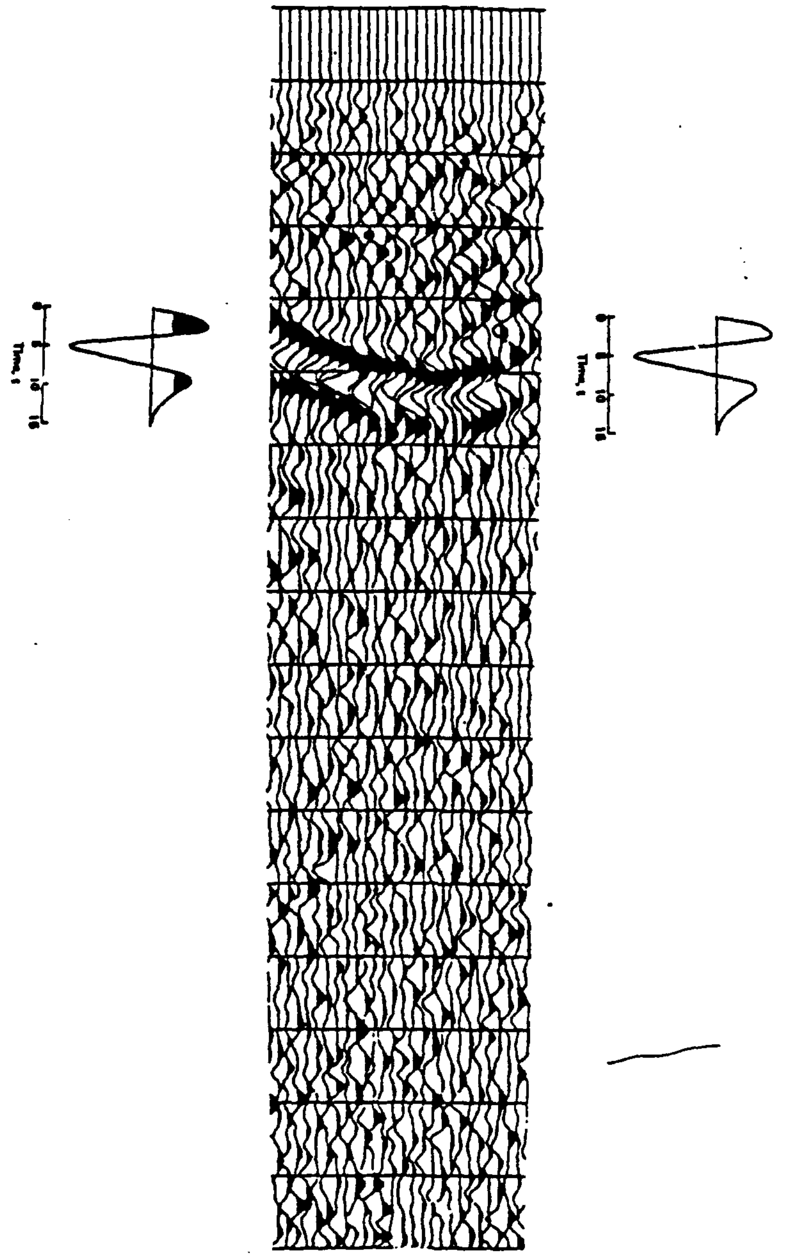


Figure 11. The wavelet shown on both sides of the seismic section schematically represents the elastic ground deformation at the point of rifle bullet impact. When this deformational wavelet is reflected back to the surface under ideal conditions it retains its doublet shape. The source wavelet on the right represents actual ground motion. The wavelet on the left is the same, except the peaks have been shaded to match the shading on a seismic section. The shading is merely to aid the interpreter. The seismic sections in this report show the bedrock reflector as a triplet rather than a doublet because of complicated near-surface wave phenomena.

A-LINE

STATION	ELEV.
0+00	5186.2
0+25	85.7
0+40	86.6
0+60	89.9
0+78	86.5
1+00	85.5
1+25	86.3
1+50	86.3
1+75	86.2
2+00	86.2
2+25	86.7
2+50	86.3
2+75	85.8
3+00	86.0
3+25	85.9
3+50	85.9
3+75	86.3
4+00	86.0
4+25	85.8
4+50	85.7
4+75	85.6
5+00	85.5
5+25	85.4
5+50	85.4
5+75	85.4
6+00	85.5
6+25	85.5
6+50	85.8
6+75	85.9
7+00	86.2
7+25	86.3
7+50	86.0
7+75	86.7
8+00	87.2

B-LINE

STATION	ELEV.
0+00	5184.9
0+25	84.8
0+50	84.8
0+75	84.7
1+00	84.7
1+25	84.7
1+50	84.6
1+75	84.5
2+00	84.5
2+25	84.6
2+50	84.3
2+75	84.0
3+00	83.4
3+15	84.4
3+30	84.7
3+50	84.4
3+65	83.0
3+75	83.4
4+00	84.3
4+25	83.8
4+50	83.7
4+75	83.6
5+00	84.0
5+25	83.6
5+50	83.9
5+75	83.8
6+00	83.7
6+25	84.2
6+50	84.2
6+75	84.1
7+00	83.9
7+25	84.5
7+50	84.9
7+75	85.1
8+00	85.4

C-LINE

STATION	ELEV.
0+00	5183.1
0+25	83.0
0+50	83.0
0+75	83.0
1+00	82.9
1+25	82.8
1+50	82.8
1+75	82.8
2+00	82.7
2+25	82.7
2+50	82.6
2+75	82.5
3+00	82.5
3+25	82.4
3+50	82.2
3+75	82.1
4+00	82.0
4+25	81.9
4+50	81.7
4+75	81.6
5+00	81.5
5+25	81.7
5+50	81.8
5+75	81.2
6+00	81.0
6+15	82.5
6+30	82.9
6+45	82.3
6+85	81.0
7+00	81.7
7+25	82.0
7+50	82.2
7+75	82.3
8+00	82.7